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A STUDY OF AIR FLOW DISTRIBUTION TEST OF THE ANNULAR COMBUSTOR --ETC(U)
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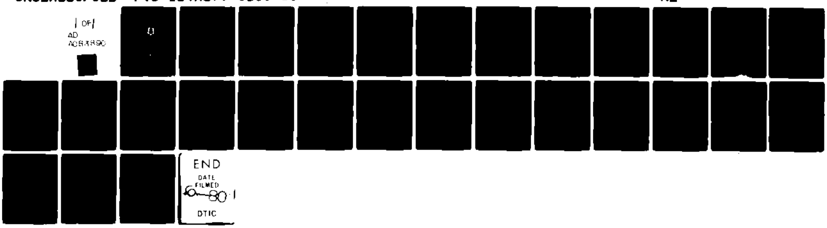

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A STUDY OF AIR FLOW DISTRIBUTION TEST
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By

Chin Jushan and Liu Chenglu

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— A Research Report —
Peking Aviation Academy

A Study of Air Flow Distribution Test of the Annular Combustor of a Jet Engine

Chin Jushan and Liu Chenglu

Abstract

This article tries to sum up the tests of air flow distribution of the large holes of a combustor by using the fan-shaped testing section of an annular combustor. We use two different testing methods: (1) hole flow characteristic curve method (or simply call hole-blocking method), and (2) annular cavity section flow method. The results of our tests by using these two methods are similar. There is no significant difference between the amount of the flow through the holes in each row and the volume of total air flow entered the combustor. This indicates that the methods of air flow distribution test suggested in this article are better than those published in the NASA documents.

As a result of comparing various air flow distribution test methods, we believe that the hole-blocking method described in this article is worth serious consideration. It would be very unfortunate if the hole-blocking method is denied completely.

1. Preface

To design annular combustor, one must understand the flow (namely the air flow distribution) of various inlet holes. Now calculation methods and procedures of air flow distribution of annular combustor have already become available but all these methods have to depend on tests as their bases. Similarly, to manufacture combustor, one must understand the changes of air flow distribution caused by the variations of combustor design (mainly the changes of geometrical size) as well as the differences of performance (such as outlet temperature distribution, ignition in space and exhaust pollution) of the combustor as a result of the change of air flow distribution. Even after the serial production of combustors has taken place, the mass stability (consistency) of the combustors is inspected and approved by the degree of changes as indicated in the result of air flow distribution test. So for combustors, air flow distribution test somehow is indispensable. At present in China, views towards various testing methods of air flow distribution remain different among different units. The purpose of this article is to introduce the methods and setups used in our tests and the results obtained from our tests, and to give our views on the different air flow distribution test methods. Thus, those who are working in the field of combustor can use them as reference.

2. Testing Setups

Testing Items The 45° fan-shaped testing section of an annular

combustor (see Figure 1). The geometrical parameters are: Of the pressurizer inlet, the inner diameter Ø is 565mm and the outer diameter Ø is 482.5mm. Of the two channels, the outer annular cavity height is 28.5 mm and the inner annular cavity height is 65mm; the outer annular cavity sectional area is 76.5 cm^2 and the inner annular cavity sectional area is 77.8 cm^2 (the above referring to the area within the 45° fan-shaped section). In our testing, we block the vortex generator as well as the small cooling holes and use three rows of holes on outer wall and three rows of holes on inner wall to make air flow distribution test. The diameters of the holes are:

	outer wall 1	outer wall 2	outer wall 3	inner wall 1	inner wall 2	inner wall 3
Number of holes	8	8	8	4	4	2
Hole diameter(mm)	19	16	23	19	16	42.5

The axial distance of holes in first row and second row is 68mm and the axial distance of holes in second row and third row is 58mm. The holes on inner wall and outer wall are arranged from front to the rear into 1, 2 and 3 rows (see Figure 2).

Testing Setups See Figure 2.

There are several points which require expanation:

1. Before entering the combustor, there is an orifice plate which is used to measure the total air flow.

2. There are two flow tubes at the downstream of the outer annular cavity and inner annular cavity. The tubes can be blocked up but they cannot

modulate or control the flow that has passed through the tube. The tubes are all well calculated, so the flow which passes through them can become known. The rear measure section can also be used to measure the flow, but,in this test, we do not use it to measure the flow which passes through the flame tube.

3. Because the flow tubes in inner and outer annular cavities, when the flow areas in flame tube and on outer wall are changed, the flow ratio of the flow which passes through flame tube and outer wall will be different. So this test in a certain degree (not completely) emulates the flow passing through the holes in each row (when making flow characteristic curve of the holes in each row). The errors in result will be analyzed and discussed in the following.

3. Testing Methods

First Method The hole flow characteristc curve method (or hole-blocking method) will be discussed along the following few points.

1. How to have the hole flow characteristic curve of each row.

This is the key point of air flow distribution test. We hope to have the relation curve of the air flow G_h* of the holes in a certain row and the pressure difference Δp_h measured at two fixed points of this row of holes (see Figure 3). Now we would like to explain how are flow G_h and pressure difference Δp_h determined when we want to measure G_h and Δp_h of the holes in

* Translator's note: Hereafter "h" is used to stand for hole or orifice; "e" for external or outer; "n" for internal or inner; "p" for plate; and "r" for release.

each row.

$G_{e3} \sim \Delta p_{e3}$ curve (see Figure 4a)

At this time, the outer annular cavity flow tubes have been blocked up. Except for one row of holes on outer wall, all the inlet holes of the flame tube are blocked up. So the G_{e3}, which passes through outer wall, is determined by the following equation:

$$G_{e3(\text{external } 3)} = G_{hp(\text{hole plates})} - G_{nr(\text{internal release})}$$

In the equation, G_{hp} is the air flow passing through flow orifice plates, and G_{nr} is, under this arrangement, the flow which passes through inner annular cavity flow tube.

Δp_{e3}, as indicated in Figure 4a, is the difference between p_{A3}, a static pressure measuring point on the outer surface of combustor, and p_{B3}, a measuring point on the inner side of outer wall of flame tube (which is close to static pressure).

$$\Delta p_{e3} = p_{A3} - p_{B3}$$

The position of A3 is at the up stream of 10mm of the holes on the outer wall, and B3 is at down stream of 13mm of that row of holes. The pressure measuring tube at B3 point is made of ∅ 0.8 steel tube connected with a fine plastic tube. They are pasted on the inner surface of the flame tube outer wall. The direction of the pressure measuring tube is perpendicular to the axial direction of the flame tube (the pressure measuring tubes of holes in each row are made of same material with same diameter). But the effect of the position of the pressure measuring points at A3 and B3 and the arrangement of the pressure measuring tubes within a certain range are not

very significant, But what is important is that the position and arrangement of the pressure measuring points when we are making $G_{e3} \sim \Delta P_{e3}$ flow charactertistic curve must be completely the same with that of the pressure measuring point of holes in that row when we are making flow distribution. In other words, once this pressure measuring tube is set up, it cannot be removed before the flow distribution test is completed. (The pressure measuring tube at B3 point can also be made of stainless fine steel tube welded on the inner surface of the tube wall). It must be pointed out that ΔP_{e3} obtained in this way cannot completely equal to the difference of the inner and outer static pressure through the holes in that row. Therefore, this ΔP_{e3} cannot be used to calculate hole flow coefficient. But, if the flow which passes through holes of that row is same (or very close) as that which passes through the holes in that row when flow distribution test is being made, then the relation of the flow with this pressure difference is constant. So we can check the foregoing flow characteristic curve ($G_{e3} \sim \Delta P_{e3}$) through ΔP_{e3} of the holes in that row when we make flow distribution test and get the flow of the holes in that row under flow distribution test. This is the important point of this method.

Similarly, we can have the relation curve of $G_{n3} \sim \Delta P_{n3}$ (see Figure 4b). In order to have the relation curves of $G_{e3} \sim \Delta P_{e3}$, $G_{n3} \sim \Delta P_{n3}$, $G_{e1} \sim \Delta P_{e1}$, and $G_{n1} \sim \Delta P_{n1}$, the testing arrangement is made as Figure 4c,d,e and f. Under such arrangement, the air flow passing through holes of each row, to a certain degree, emulates the bypass flow ratio at the position of each hole. At this time the bypass flow ratio are as follows:

$$\frac{G_{er}}{G_{e2}}, \quad \frac{G_{nr}}{G_{n2}}, \quad \frac{G_{er}}{G_{e1}}, \quad \frac{G_{nr}}{G_{n1}}$$

Here "to a certain degree it emulates" means that the foregoing bypass flow ratio are not completely same as those when flow distribution is being made, namely:

$$\frac{G_{er}}{G_{e2}} \neq \frac{G_{e3}}{G_{e2}},$$

$$\frac{G_{nr}}{G_{n2}} \neq \frac{G_{n3}}{G_{n2}},$$

$$\frac{G_{er}}{G_{e1}} \neq \frac{G_{e3} + G_{e2}}{G_{e1}},$$

$$\frac{G_{nr}}{G_{n1}} \neq \frac{G_{n3} + G_{n2}}{G_{n1}}$$

This is because of the limitation that the inner and outer annular flow tubes are not modulatable. From Figure 6, we can see the impact of the bypass flow ratio upon flow coefficient. Very great is the differeence between the situation that the bypass flow ratio is zero (namely $\frac{G_{er}}{G_{e2}} = 0$ or $G_{er} = 0$) and that the bypass flow ratio is not zero (for instance the bypass flow ratio is 1). But, if the changes of the bypass flow ratio are within a definite range (for example from 2 to 3), there is still impact but the impact is less significant. By now, we have had the flow characteristic curves of the holes in each row as indicated in Figure 3.

2. Air flow distribution test

After having had flow characteristic curves of the holes in each row, we maintain each pressure measuring point unchanged absolutely. Then we open the holes in six rows simultaneously (see Figure 2) and block up the inner as well as the outer annular cavity flow tubes. At the same time, we read out Δp_{e1}, Δp_{e2}, Δp_{e3}, Δp_{n1}, Δp_{n2} and Δp_{n3}. Checking the curves in Figure 3, from the numerical value of Δp_h to determine G_{e1}, G_{e2}, G_{e3}, G_{n1}, G_{n2} and G_{n3}, and at the same time to measure G_{hp}. By now the air flow totally enters the flame tube. Hereby we have the flow distribution of the holes in each row $\frac{G_{hi}}{\Sigma G_{hi}}$. The applicability of this test can be approved by the following equation:

$$\frac{\Sigma G_{hi}}{G_{hp}} \text{ ought to equal to 1,}$$

namely the tilt of $\frac{\Sigma G_{hi}}{G_{hp}}$ away from 1, the smaller the better. (But, however, even if $\frac{\Sigma G_{hi}}{G_{hp}} = 1$, it does not necessarily means that there is no error at all in the relation of flow distribution. This is the characteristic of flow distribution test.)

Second Method Annular cavity section flow method

At a point of 10mm in front of the holes in each row, arrangement for measuring total static pressure is made. In order to be able to measure the air flow in annular cavity accurately from the annular cavity total static pressure, before starting air flow distribution test, we calculate the flow volume of each target of total static pressure measuring, namely

$$G_{\substack{\text{annular}\\\text{cavity}}} = k \cdot \frac{m \cdot F \cdot P^* q(\lambda)}{\sqrt{T^*}} .$$

By any single flow G, and P^*, F, T^*, λ, which passes through a certain annular cavity to determine the total static pressure measuring target in each row, and the coefficients for flow calculation are listed in the following:

	outer annulus 1	outer annulus 2	outer annulus 3	inner annulus 1	inner annulus 2	inner annulus 3
k	0.983		1.28	1.03	1.37	1.35

In air flow distribution test, the foregoing six targets are installed simultaneously, and the flow volume through the holes in each row can be determined by the following equation:

$$G_{hi} = G_{\substack{\text{annular cavity}\\ \text{before holes}}} - G_{\substack{\text{annular cavity}\\ \text{behind holes}}}$$

G_{e3} and G_{n3} can be determined by the annular cavity flow before the holes.

4. Testing Results

We made several air flow distribution tests under inlet M number condition. The inlet M numbers are:

Testing state 1: combustor inlet M = 0.264

Testing state 2: combustor inlet M = 0.294

Testing state 3: combustor inlet M = 0.307

The results:

(Translation of the headings of the following table:
a. hole flow characteristic method; b. annular cavity section flow method;
c. inlet with nonhomogeneous orifice plates; d. testing state 1, 2, 3; 1, 2, 3; 1,2)

methods / flow distribution parameters	area percentage $F_i/\Sigma F_i$	a 孔流量特性法			b 环腔截面流量法			c 进口带不均匀孔板	
		d 试验状态1	试验状态2	试验状态3	试验状态1	试验状态2	试验状态3	试验状态1	试验状态2
G_{e1} kg/sec.		0.1615	0.155	0.161	0.1334	0.1484	0.1456	0.137	0.1495
$\frac{G_{e1}}{G_t}$ %	18.9	17.12	16.99	16.91	17.6	17.81	16.76	16.96	17.05
G_{e2} kg/sec		0.1035	0.113	0.117	0.0902	0.1052	0.1163	0.1015	0.107
$\frac{G_{e2}}{G_t}$ %	13.62	12.52	12.39	12.29	12.43	12.62	13.39	12.56	12.2
G_{e3} kg/sec		0.253	0.2845	0.295	0.2342	0.2565	0.292	0.2565	0.2595
$\frac{G_{e3}}{G_t}$ %	27.73	30.61	30.97	30.98	30.91	30.78	31.31	29.27	29.18
G_{n1} kg/sec		0.066	0.072	0.0755	0.0665	0.0615	0.0578	0.067	0.071
$\frac{G_{n1}}{G_t}$ %	9.47	7.98	7.89	7.93	8.75	7.37	6.65	8.29	8.09
G_{n2} kg/sec		0.052	0.056	[illegible]	0.0166	0.0281	[illegible]	0.052	0.055
$\frac{G_{n2}}{G_t}$ %	6.71	6.49	6.14	6.09	1.93	3.37	3.37	6.44	6.38
G_{n3} kg/sec		0.2105	0.2335	0.2655	0.2152	0.2337	0.2661	0.214	0.235
$\frac{G_{n3}}{G_t}$ %	23.65	25.47	25.6	25.79	28.39	28.06	28.4	26.49	26.8
G_t = ΣG_i kg/sec		0.8265	0.912	0.952	0.7519	0.8334	0.8686	0.808	0.877
G_{np} kg/sec		0.783	0.872	0.913	0.783	0.873	0.913	0.728	0.792
$\frac{G_{et}}{G_t}$ %	60.15	60.25	60.36	60.20		61.3	61.5	58.78	58.84
$\frac{G_{nt}}{G_t}$ %	39.85	39.75	39.64	39.80		38.70	38.5	41.22	41.16

(Translator's note: "t" stands for total)

* Inlet with nonhomogeneous orifice plates test data are treated according to the hole flow characteristic method.
** $G_{et} = G_{e1} + G_{e2} + G_{e3}$. *** $G_{nt} = G_{n1} + G_{n2} + G_{n3}$.

Using hole flow characteristic curve to measure flow distribution, $\Sigma G_i = G_t$, and from flow orifice plates to measure the total flow volume G_{hp}. Their ratio are:

	Inlet without nonhomogeneous orifice plate			Inlet with nonhomogeneous orifice plate	
Testing state	1	2	3	1	2
$\frac{\Sigma G_i}{G_{hp}}$ %	105.55	104.47	104.27	111	111

The results of the foregoing tests provide explanations for the points that follow:

1. The air flow distribution obtained from two testing methods is fundamentally similar except that there is some difference in flow distribution of the holes in three rows on the inner wall. It needs further tests and reseach to explain the reason.

2. The flow distribution and area percentage obtained by using hole flow characteristic curves are generally close, and $\frac{\Sigma G_i}{G_{hp}}$ and 100% are relatively closer. This means that there is no great error in the testing methods.

3. A comparison of the flow distribution test published in NASA document[1] and the tests introduced by this article can prove that the

(1) NASA TN-D 7878, N75-28072

results of our tests are better than the result in that document (see appendix 1), and the reasons are:

a. When the inlet is without nonhomogeneous orifice plates, the tilt of $\Sigma G_i / G_{hp}$, which is obtained from flow characteristic curves as has been descibed ib this article, away from 1 is smaller.

b. The offset value in this article is unilateral. But in NASA document, it uses total static pressure measuring to calculate speed distribution and then from accumulative to have flow volume (in this article, the annular cavity section flow is calculated through flow). So the effect of uneven directional distribution around the flow field in the annular channel of the combustor is very great, and the number of the total static pressure measuring targets in the channel is always limited (usually 3 or 4). This is very important in the annular combustors. The methods introduced in this article will not have the effect of uneven directional distribution around the flow field in the annular channel.

4. There is a correspondent relationship between area percentage and flow distribution obtained from hole flow characteristic curves. As the measuring result indicates, the flow of the main combustion holes (outer wall 1 and inner wall 1) and the intermediate holes (outer wall 2 and inner wall 2) is smaller than area percentage, and the flow of mixed holes (outer wall 3 and inner wall 3) is larger than area percentage. Such tendency is in accord with the result of studies concerning hole flow coefficient.

In making flow distribution test, the ratio of mixed hole flow and main combustion hole flow are $\frac{C_{dx}}{C_{dm}} \cdot \frac{F_x}{F_m} \cdot \left(\frac{\rho_x}{\rho_m}\right)^{\frac{1}{2}} \cdot \left(\frac{\Delta p_x}{\Delta p_m}\right)^{\frac{1}{2}}$.

(Translator's note: "x" stands for mixed and "m" for main)

As $\rho_x \approx \rho_m$, $\Delta p_x \approx \Delta p_m$, the flow ratio should be basically corresponding with the area percentage, but not equal to each other and the difference lies in the ratio of flow coefficient. The flow coefficient of mixed holes is larger than that of the main combustion holes (mainly because of the effect of bypass flow ratio). By the way, if a comparison is made between the mixed hole flow when flow distribution test is being made and that of the holes in the same row when combustion is taking place, the pressure decrease of mixed holes under combustion is larger than that when flow distribution test (cold blowing) is being made (under the condition that the inlet mean total pressure and inlet M number are same). So under the condition of combustion, the flow of mixed holes is much larger than area percentage, and the flow of main combustion holes is much smaller than area percentage.

5. The flow distribution under different inlet M number basically shows no difference.In this respect, the result of using hole flow characteristic curve method will be much better.

6. The annular cavity section flow method has the following defects: Of the hole flow obtained by subracting the front section cavity flow from the rear, if there is some error (for instance, it appears smaller) in measuring an intermediate section, it will make the flow of the holes in two rows all have errors (one becomes larger and the other becomes smaller). As a result, the flow distribution relation cannot be accurate. At the same time, it will be rather difficult to use section flow to determine the air flow volume of cooling hole band and vortex generator.

From the above situation, it becomes clear that although the two

different kinds of methods can be used, in the opinion of the authors of this article, however, it would be better to use hole flow characteristic curve method (hole-blocking method). What deserves our consideration is under the condition of annular combustor to select what method which is suitable, basically practical and able to give entire air flow distribution (including flow interferometer, larger holes small holes and cooling holes). and it is not to make comparison under the condition of simple rectangular channel and simple holes.

5. Discussion

The following few points must be made sure if we want to have useful results of flow distribution test by using hole flow characteristic curve method.

1. When making flow characteristic curves of holes in each row, the position and arrangement of pressure measuring points must be completely the same as in mkaing flow distribution test. This is not difficult to achieve if the pressure measuring points are fixed (by welding, pasting or sticking).

2. All of the blocked spots are absolutely not allowed to leak when flow characteristic curves of holes in each row as well as flow distribution are being made. Because the pressure difference between the inside and outside of the flame tube is not great, this requirement is easy to meet. Some sealing wax added to plaster will do the work.

3. Under the two conditions mentioned above, the air pressure and temperature through the holes in each row must be the same. This can be made like in a test which requires to guarantee having same air pressure and

temperature. But, because the pressure loss under two different situations is not completely the same, the air pressure through the holes can have some slight difference, but the effect of this is so insignificant that it can simply be ignored.

4. In order to guarantee, under the above two different conditions, the situation of the flow which passes through the holes being identical, it requires relatively detailed consideration.

So far as the mixed holes are concerned, it is easier to guarantee bypass flow ratio, but there are differences in the outlet flow of the holes (see Figure 5). The question is how great is the effect of this difference? The study of hole flow coefficient test indicates (see Figure 5c) that after the air flow through holes at $\frac{\rho_j V_j^2}{\rho_\infty V_\infty^2}$ becomes larger than 10, the change of V_∞ produces no impact upon the hole flow coefficient. When the condition as indicated in Figure 5a (when hole flow is optimum) is $\frac{\rho_j V_j^2}{\rho_\infty V_\infty^2} \to \infty$, under the condition of combustion, approximately $\rho_j \approx 2 \cdot \rho_\infty$, $V_j \approx 2 V_\infty$ (namely $T_\infty \approx 2 \cdot T_j$, $M_j \approx 3 M_\infty$) $\therefore \frac{\rho_j V_j^2}{\rho_\infty V_\infty^2}$ close to 8 - 10 (this is because most of the flow coefficient data used in the combustor are the testing data when the air flow without transverse side $V_\infty \to 0$). In flow distribution test (cold blowing), if the air flow in the flame tube equals to each other, then $\rho_{K\infty} > \rho_{H\infty}$, $V_{K\infty} < V_{H\infty}$ and $\rho_{K\infty} \cdot V_{K\infty} = \rho_{H\infty} V_{H\infty}$ $\therefore \rho_{K\infty} V_{K\infty}^2 < \rho_{H\infty} V_{H\infty}^2$ So it is not difficult to satisfy the condition of $\frac{\rho_j V_j^2}{\rho_\infty V_\infty^2} > 10$ in flow distribution test (if only $M_j > 3 M_\infty$).

For the intermediate holes, because V_∞ is much smaller, there is no

possibility to have a situation of $\frac{\rho_j V_j^2}{\rho_\infty V_\infty^2} < 10$, (and it is even more impossible for the main combustion holes).

It is very important to secure the bypass flow ratio for the intermediate holes and the main combustion holes. This means that under the above two conditions, $\frac{G_{er}}{G_{e1}} = \frac{G_{e2}}{G_{e2}}$, $\frac{G_{nr}}{G_{n1}} = \frac{G_{n2}}{G_{n2}}$. The reason for this is that the difference of bypass flow ratio will affect the flow coefficient of the holes. The ideal situation would be that the inner as well as the outer annular flow tubes can all be modulated and thus the bypass flow ratio can be the same. Under the condition as described in this article, although we failed to achieve it completely, as indicated in Figure 6, after the bypass flow ratio becomes larger than 2, there are some slight changes (for instance, from 2 to 3), there has caused no serious effect. In the tests described in this article, due to the fact that the inner as well as the outer annular cavity flow tubes are not modulatable, when making flow characteristic curves of $G_{e1} \sim \Delta p_{e1}$, $G_{e2} \sim \Delta p_{e2}$, the bypass flow ratio is smaller than that when flow distribution is made. Such a result will make the flow ratio of the main combustion holes and the intermediate holes (especially the holes on outer wall) in flow distribution larger than what they really are. At the same time, because $\frac{\rho_j V_j^2}{\rho_\infty V_\infty^2}$ of the mixed holes is not completely guaranteed, the flow ratio of the mixed holes is also larger than what they should really be. This helps to explain why the $\frac{\Sigma G_i}{G_{HK}}$ obtained by using this method is always unilaterally larger than 1.

In short, for the mixed holes, $\frac{\rho_j V_j^2}{\rho_\infty V_\infty^2}$ must be guaranteed and for the intermediate holes and the main combustion holes, bypass flow ratio has to

be assured.

From now on, of air flow distribution test by hole flow characteristic curve method, we can continue our study on the following aspects:

1. Combustor. We do not want to make holes on the outer cover of a combustor or to set up pressure measuring tubes, nor do we want to install inner or outer annular cavity flow tubes (the outer cover of the combustor and the flame tube need to be changed). Then we can:

a. move the pressure measuring points from the outer cover of combustor to the outer surface of the flame tube wall, and change to use fine steel tube which can be fixed by welding or pasting;

b. not install inner or outer annular cavity flow tube but use the following methods to determine the flow characteristics of the holes in each row:

(i) Mixed holes G_{e3}, the method is same as above, but $G_{nr} = 0$, therefore $G_{hp} = G_{e3}$; (ii) Intermediate holes G_{e2}, to open the holes in 2 and 3 rows on outer wall, $G_{e2} = G_{hp} - G_{e3}$. Now G_{e3} is determined by $G_{e3} \sim \Delta P_{e3}$ obtained from (i); (iii) Main combustion holes G_{e1}, to open the holes in 1, 2 and 3 rows on outer wall, $G_{e1} = G_{hp} - G_{e2} - G_{e3}$. Now G_{e2} and G_{e3} can be obtained from curves of $G_{e2} \sim \Delta P_{e2}$ and $G_{e3} \sim \Delta P_{e3}$ which come from (i) and (ii); (iv) To open the holes in 1, 2 and 3 rows on vortex generator and outer wall and use $G_v = G_{hp} - G_{e1} - G_{e2} - G_{e3}$ to determine the air flow volume of vortex generator; (v) In the same fashion to have the characteristic curves of the holes in each row; (vi) To compare the characteristic curve of $G_v \sim \Delta P_v$ that

(Translator's note: "v" stands for vortex)

is obtained by opening the holes in 1, 2 and 3 rows on vortex generator and inner wall with that which comes from (iv), and check the reliability. The rest methods are same as above.

c. In order to have the cooling air flow distribution, we first put a certain cooling hole band together with one row of large holes to have their flow distribution, and in a way we then separate the flow of the large holes and the cooling holes.

2. If it is for study (mainly for checking the flow distribution calculation method), the inner as well as the outer annular cavity flow tubes can be made into that which is modulatable so as to insure bypass flow ratio. We can also insert a tube into the rear measuring section of a flame tube through the air of which the volume has been known so as to insure $\frac{\rho_j V_j^2}{\rho_\infty V_\infty^2}$ of mixed holes.

6. Conclusive Remarks

1. The combustor air flow distribution test method obtained by using hole flow characteristic curve method (hole-blocking method) is worth further exploring.

2. Taking detailed measure to provide condition that can insure the sameness of the flow situation.

3. The authors of this article believe that the combustor air flow distribution test is primarily a matter of engineering nature, and to a large degree it is determined by suitable testing arrangement and experience. What is more important is the association of air flow distribution and the

property of combustor or the result of modulation that can be achieved through the accumulation of using the accustomary and familiar air flow distribution testing methods. Otherwise, it will not make much practical sense to expect high degree of accuracy in the air flow distribution test. The reasons are: (a) the air flow distribution when there is cold blowing is not the same as that under a condition of combustion, and (b) after all, what kind of flow distribution can be the best for a concrete combustor? The answer to such a question basically comes from experience.

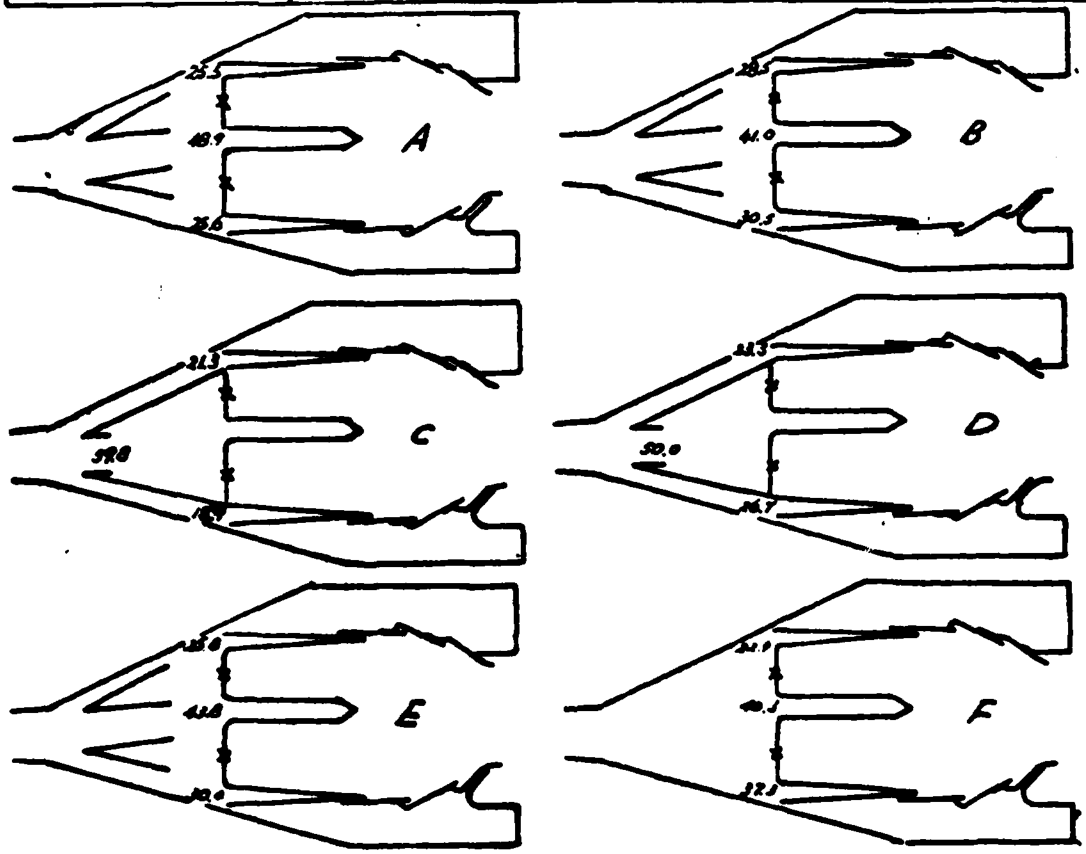
So the following example may be somehow found very interesting. Of an annular combustor, to compare the air flow distribution calculated according to calculation procedure with the testing results and also measure the outlet temperature distribution of the combustor under that condition. Then to block up half of the area of the mixed holes (to block up every other hole or to add an impeding ring to cover up half of the area), to calculate the flow distribution changes according to the calculation procedure. From test to have the flow distribution changes and in the same state to measure the changes of the outlet temperature distribution. Finally, using the outlet temperature distribution calculation method, which bases half on experience and half on theory, to calculate the corresponding changes of the outlet temperature distribution after the air flow distribution has changed, and to compare it with the results of tests.

4. The authors of this article believe that it is better to use air than water as medium to make combustor air flow distribution test. Our work is far from perfect and our views may be incorrect. We welcome corrections from those who are working in the field.

Appendix 1 (From NASA TN - D 7878 Figure 13)

The author of NASA TN-D 7878 has measured the distribution of three air flows of an annular combustor. There are six different situations of combustor as indicated in the following diagrams and in the following table are their $\frac{\Sigma G_i}{G_{\#0}} = \frac{G_1 + G_2 + G_3}{G_{\#0}}$,

Combustor	A	B	C	D	E	F
$\Sigma G_i / G_{\#0}$ %	83.6	89.4	97.5	110.7	89.2	90



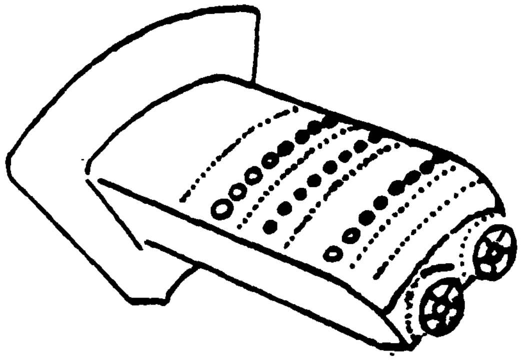


Figure 1 Fan-shaped testing article

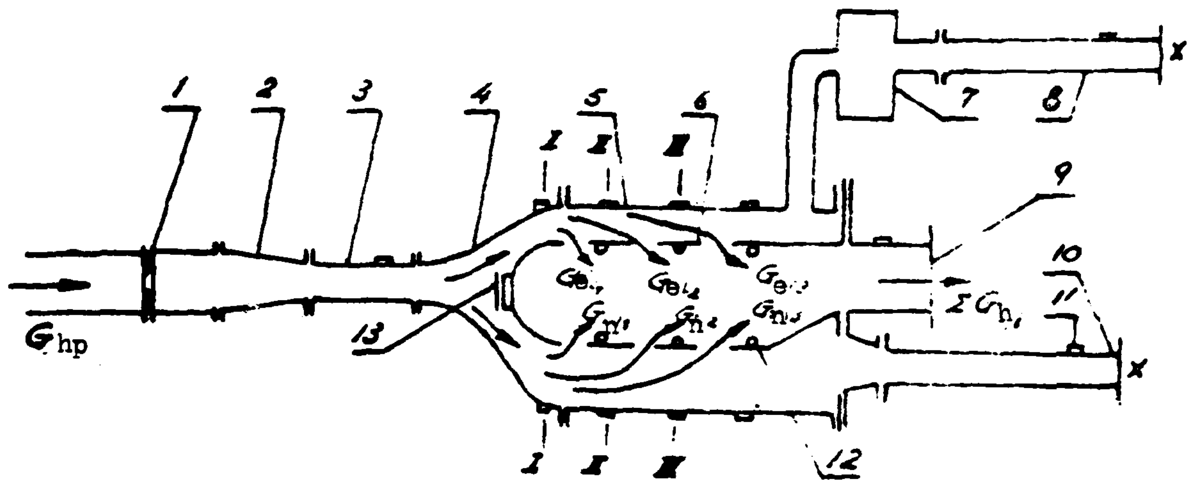


Figure 2 Testing setup

1. Measuring orifice plate (G_{hp}) of total flow passing through combustor, 2. front built-up connection section, 3. front measuring section, 4. pressurizer, 5. combustor outer cover, 6. large flame tube, 7. air collecting cavity, 8. outer annular cavity flow tube, 9. rear measuring section, 10. inner annular cavity flow tube, 11. measuring station of each total static pressure, 12. fine steel tube(Ø 0.8) pressure measuring point sticked behind holes of each row on the inner surface of flame tube, 13. blocking materials (such as plaster).

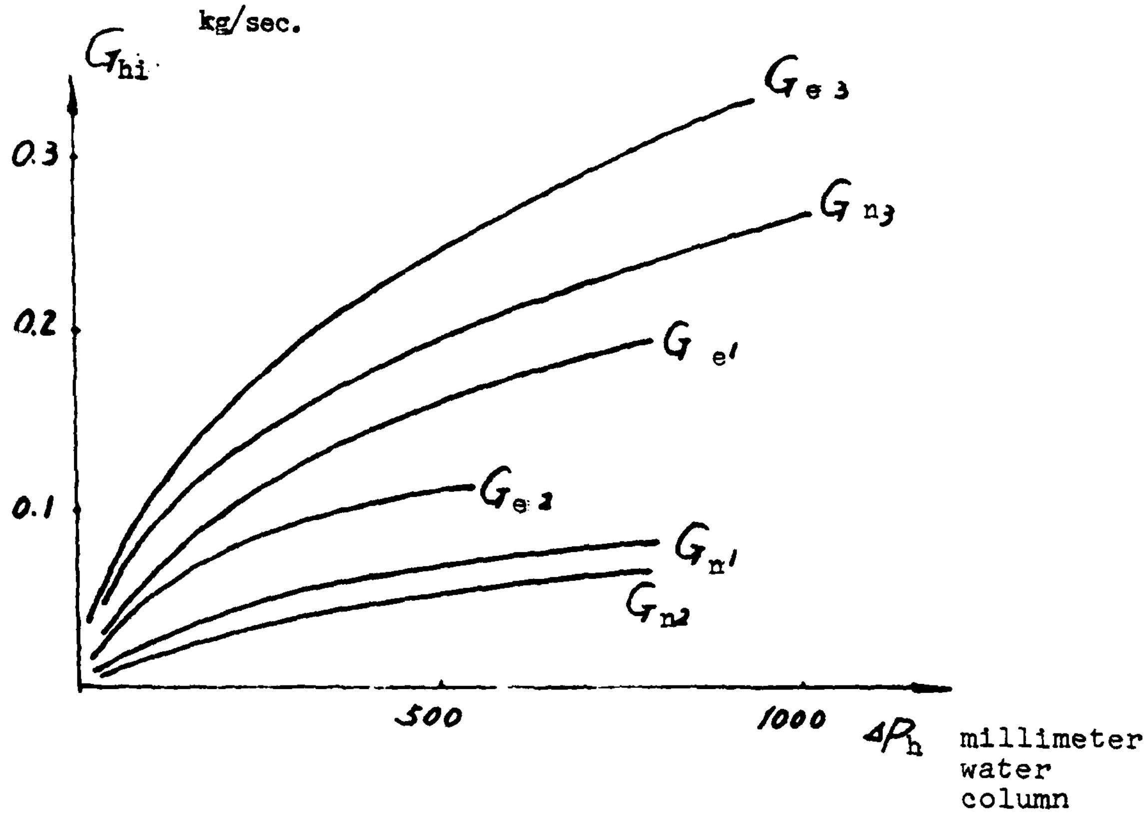
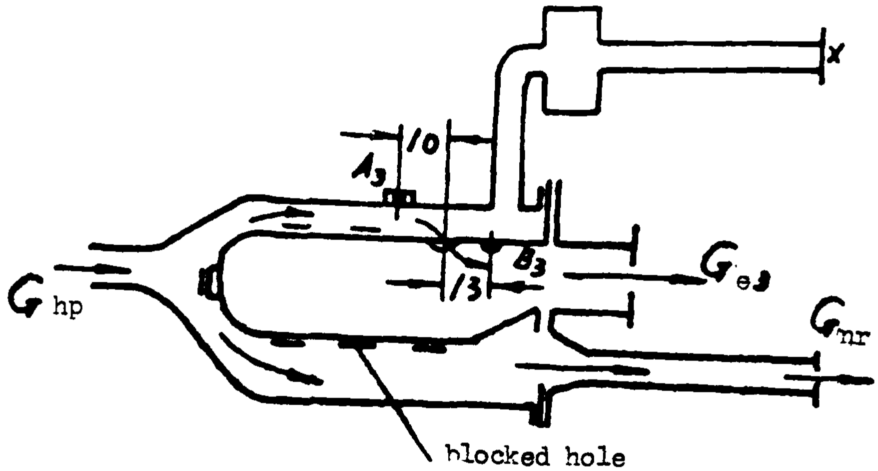


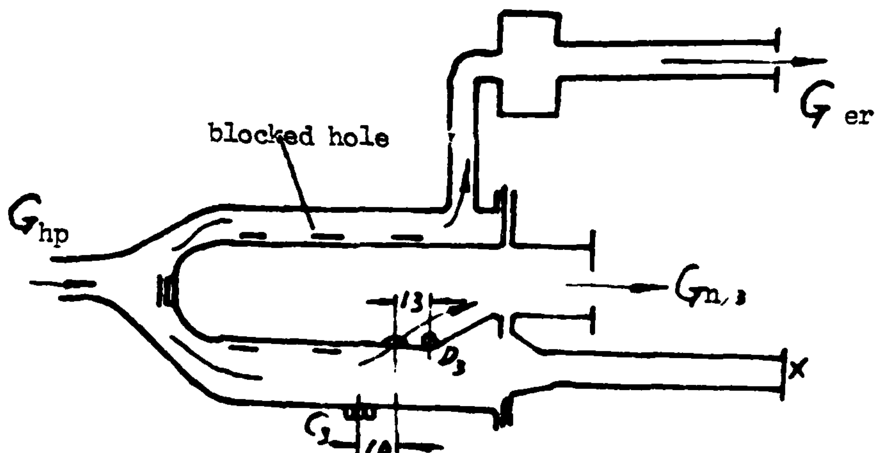
Figure 3 Flow characteristic curves of the holes in each row



$$G'_{e_3} = G_{hp} - G_{nr}$$

$$\Delta P_{e_3} = P_{A_3} - P_{B_3}$$

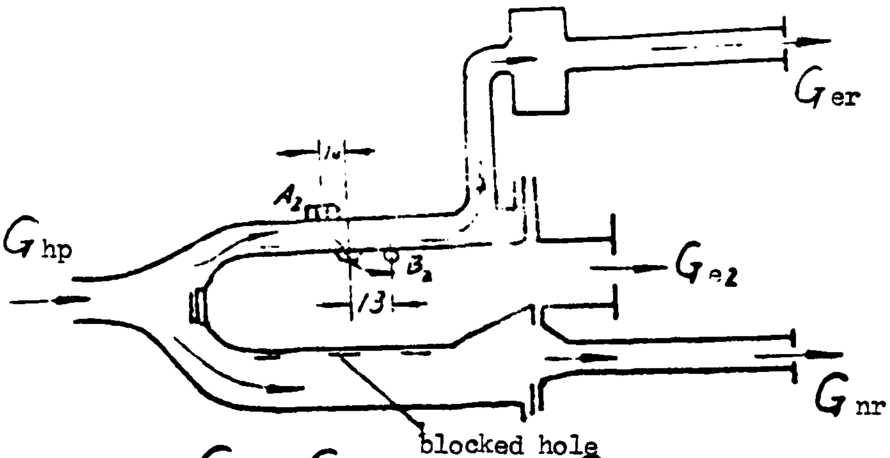
Figure 4 a



$$G_{n_3} = G_{hp} - G_{er}$$

$$\Delta P_{n3} = P_{C_3} - P_{D_3}$$

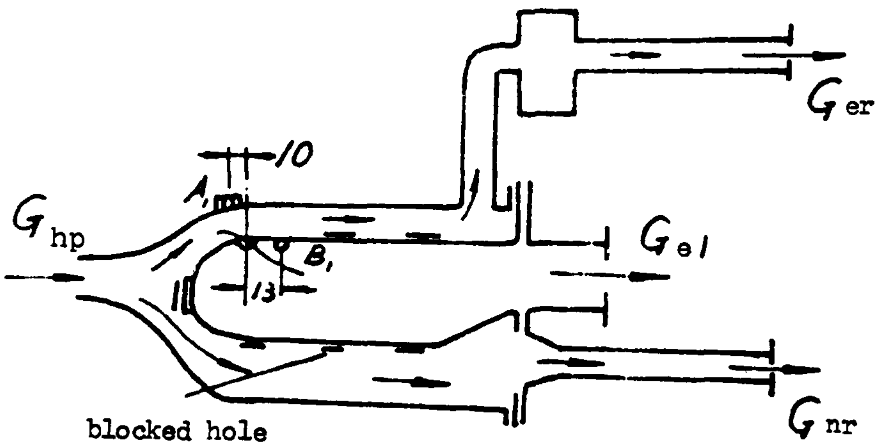
Figure 4 b



$$G_{e2} = G_{hp} - G_{er} - G_{nr}$$

$$\Delta P_{e2} = P_{A2} - P_{B2}$$

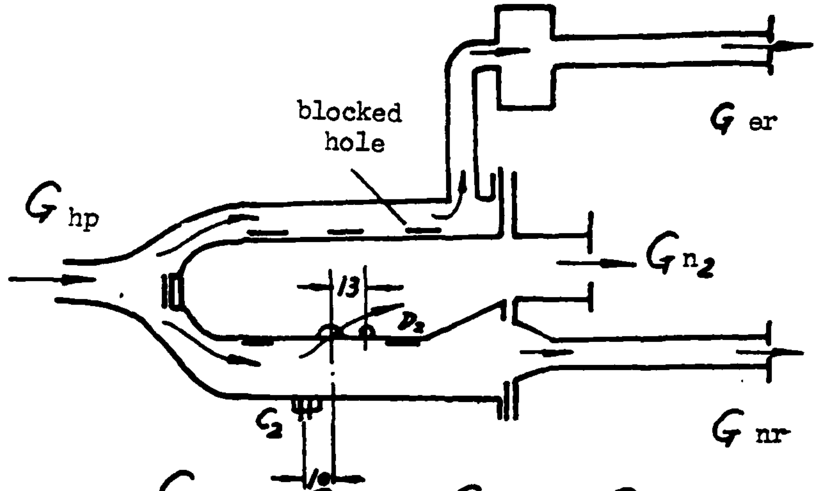
Figure 4 c



$$G_{e1} = G_{hp} - G_{er} - G_{nr}$$

$$\Delta P_{e1} = P_{A1} - P_{B1}$$

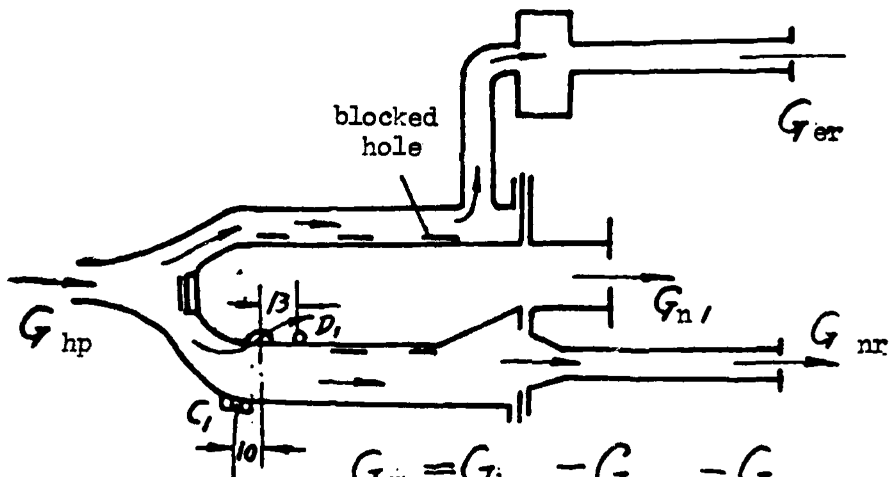
Figure 4 e



$$G_{n2} = G_{hp} - G_{er} - G_{nr}$$

$$\Delta P_{n2} = P_{C2} - P_{D2}$$

Figure 4 d



$$G_{n1} = G_{hp} - G_{er} - G_{nr}$$

$$\Delta P_{n1} = P_{C1} - P_{D1}$$

Figure 4 f

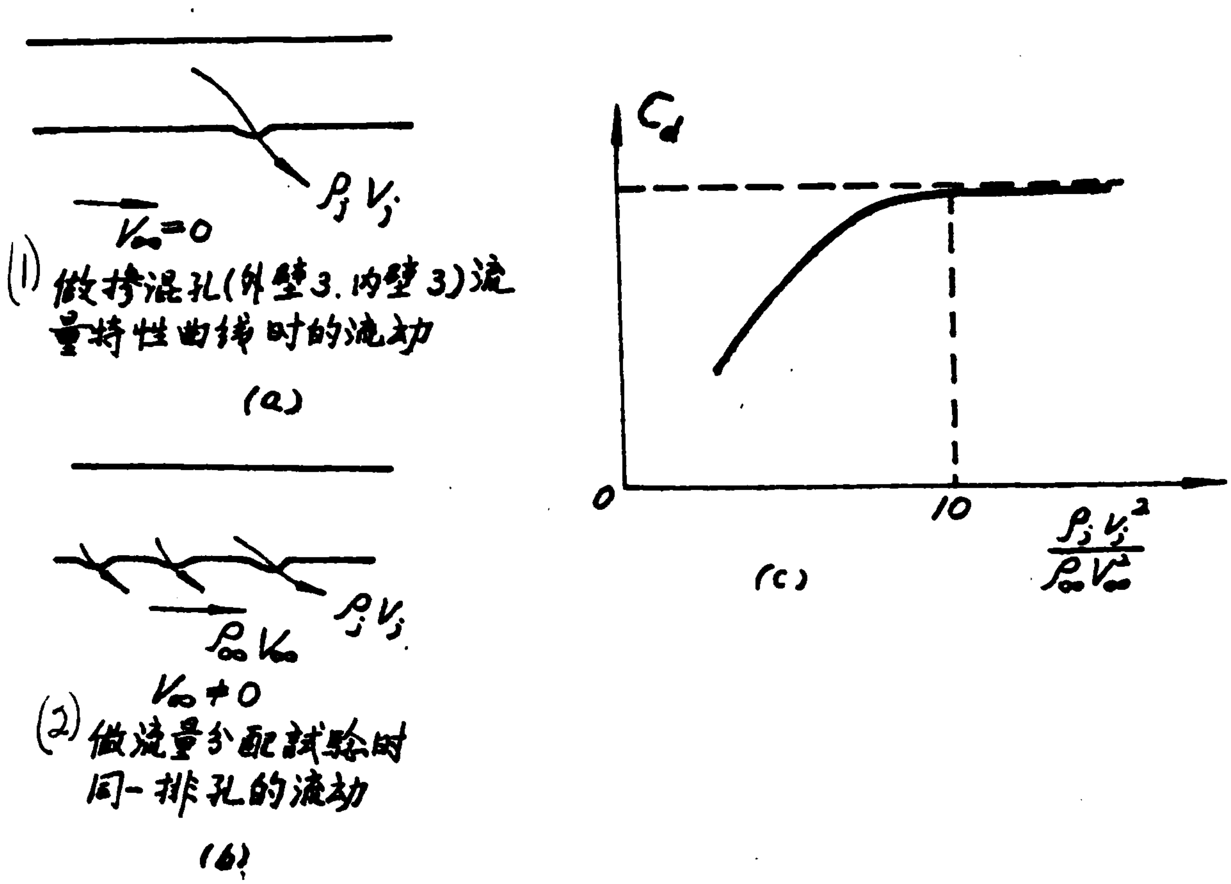


Fig. 5.

Key: (1) Flow with mixed hole (outside wall 3, inside wall 3) flow characteristic curve. (2) Flows of same inlet hole during flow distribution test.

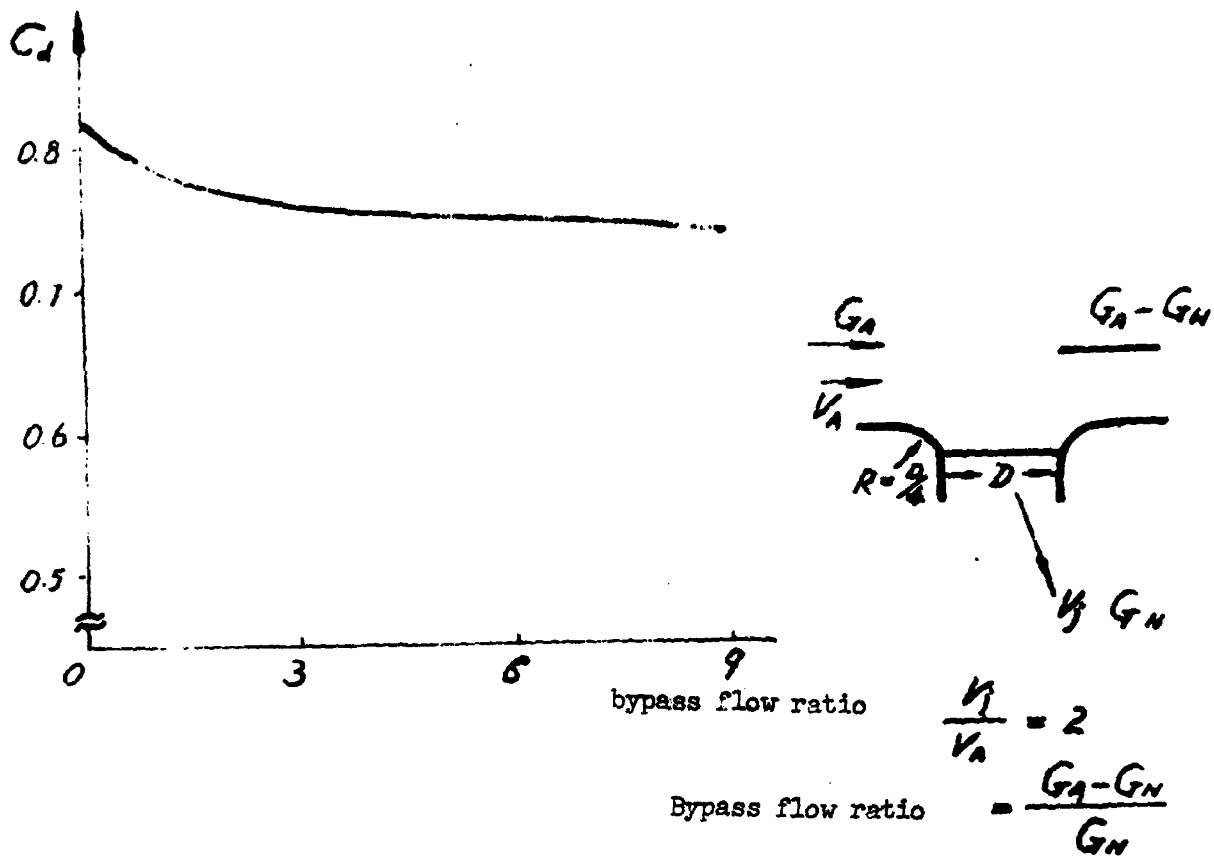


Figure 6 The change of hole flow coefficient according to bypass flow ratio (The data come from the flow Coefficient test data of the side-rolled-up hole of R = D/L when $\frac{V_j}{V_A} = 2$)